INNOVATIVE TECHNOLOGY
Summary Report

DOE/EM-0505

# Empore$^{TM}$ Membrane Separation Technology

Deactivation and Decommissioning
Focus Area

*Prepared for*
Office of Environmental Management
Office of Science and Technology

February 2000

Innovative Technology
Summary Report

# EMPORE™ Membrane Separation Technology

OST/TMS ID 1543

Deactivation and Decommissioning
Focus Area

*Demonstrated at*
Argonne National Laboratory-East
Argonne, Illinois

INNOVATIVE TECHNOLOGY

Summary Report

## *Purpose of this document*

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine whether a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at http://ost.em.doe.gov under "Publications."

# TABLE OF CONTENTS

SECTION 1

# SUMMARY

## Technology Description

The objective of the Large-Scale Demonstration Project (LSDP) is to select and demonstrate potentially beneficial technologies at the Argonne National Laboratory-East (ANL) Chicago Pile-5 Research Reactor (CP-5). The purpose of the LSDP is to demonstrate that by using innovative and improved decontamination and decommissioning (D&D) technologies from various sources, significant benefits can be achieved when compared to baseline D&D technologies. This report describes a demonstration of Empore™ membrane separation cartridge for treating radioactively contaminated water at CP-5. This demonstration is part of the CP-5 LSDP sponsored by the U.S. Department of Energy's (DOE) Office of Science and Technology's Decontamination and Decommissioning Focus Area (DDFA).

The objective of the treatment of radioactivity contaminated water during the D&D process is to purify effluent water in order to meet regulatory criteria for release of wastewater. The applicable regulation for ANL is the derived concentration guides in DOE Order 5400.5, "Radiation Protection of the Public and the Environment." To achieve this objective, the Empore™ membrane separation cartridge was demonstrated in September 17 - 23, 1996.

The Empore™ membrane separation technology was developed and patented by 3M and provides a method for enmeshing sorbent, surface-active particles in a web-like matrix which is formed into a membrane. This membrane is designed to have the integrity and handling strength for long term performance under high levels of radiation across a board range of pH and has a high particle surface availability. It can be used to selectively remove specific contaminants down to predetermined detection levels at high flow rates. To process water, the membrane is configured into a cartridge, which is then installed in commercially available filter housings. Analysis of output water samples from the demonstration apparatus indicated Cs-137 and Co-60 concentrations of less than 0.02 pCi/ml. Approximately 4500 gallons of water from the CP-5 storage pool were treated during the demonstration. After use the cartridges were packaged and disposed of as low level radioactive waste.

Figure 1. Empore™ Membrane Separation Cartridges (Foreground)

Figure 2. Demonstration Filter System

## Technology Status

This technology is not yet available commercially, although it has been previously field tested (see References, Appendix A). Removal of cesium, strontium and technetium has been demonstrated previously at other sites, including the N-Basin at the Hanford site. At that site, cartridges were loaded with 100 grams of sorbent material.

The cartridges used for ion removal as developed by 3M are configured nearly identically to standard cartridge filters used for particulate removal from gases or liquids. Therefore, the cartridges can be used in cartridge filter housings which have standard piping connections that are currently available commercially. 3M estimates that a single cartridge could process 160,000 gallons of water. This assumes that adequate radiation shielding and particulate prefiltering are provided. This is also dependent on the amount of stable radiological isotope in the water. 3M expects a production 10-inch cartridge to have a rated flow of 1 gpm. Multiple cartridges can be used to increase flow rate to the desired value.

The results of the field tests, including the CP-5 test, will be used to scale-up the design for a full-scale system.

## Key Results

The key results of the demonstration are as follows:

| | |
|---|---|
| Flow Rate: | 0.5 gpm using a 10 inch length cartridge |
| Total Volume Throughput: | 4,500 gallons |
| Radiological Input: | Cs-137 - approximately 0.60 pCi/ml |
| | Co-60 - approximately 0.20 pCi/ml |
| Radiological Output: | Cs-137 - approximately 0.003 pCi/ml |
| | Co-60 - <0.02 pCi/ml (less than MDA) |
| Demonstration Duration: | 150 hours |
| Total Waste: | 0.56 Cu Ft. LLRW |

## Contacts

### Technical

Thomas M. Kafka, 3M New Products Department, Phone: (612) 733-8065

Keith M. Hoffmann, 3M New Products Department, Phone: (612) 575-1795

### Demonstration

David Black, Test Engineer, Argonne National Laboratory, (630) 252-6030 dbblack@anl.gov

### CP-5 Large-Scale Demonstration Project or Strategic Alliance for Environmental Restoration

Richard C. Baker, U.S. Department of Energy, Chicago Operations Office, (630) 252-2647, richard.baker@ch.doe.gov

Steve Bossart, Federal Energy Technology Center, (304) 285-4643, sbossa@metc.doe.gov

Terry Bradley, Strategic Alliance Administrator, Duke Engineering and Services, (704) 382-2766, tlbradle@duke-energy.com

### Licensing Information

No licensing or permitting activities were required to support this demonstration.

### Web Site

The CP-5 LSDP Internet address is http://www.strategic-alliance.org.

SECTION 2

# TECHNOLOGY DESCRIPTION

## System Configuration and Operation

The 3M membrane separation technology provides a method for enmeshing surface-active particles in a net-like matrix of fibrils to form a membrane which can be used for water clean-up. The membrane has good integrity and handling strength and a high particle surface availability. Various ion exchange materials can be embedded into the membrane, depending on the ions which need to be removed. The membrane is configured as a standard cartridge filter such that it can be used in a standard commercial cartridge filter housing. The technology is based on selective sorbent technology instead of traditional wet chemical extraction, chemical precipitation, or large ion exchange columns. The technology provides the capability of removing radioactive contaminants to below detectable levels, at high flow rates. Contaminants are concentrated in the cartridges, resulting in a reduction in the secondary waste stream.

This technology is designed to remove beta and gamma emitting particles which are soluble constituents in water, and is capable of removing any constituents that could be removed by conventional ion exchange columns. The ion exchange materials in the Empore™ membranes used at the CP-5 demonstration were selected specifically by 3M for removing soluble Cs-137 and Co-60 in aqueous solution. By proper selection of the ion exchange material embedded in the Empore™ membrane, it is possible to tailor the membrane to remove the specific isotopes of concern in the storage pool water at the CP-5 Reactor. For demonstration purposes, the membrane technology was compared against the baseline technology of shipping the water in tanks to an on-site evaporator facility for treatment, and the use of mobile treatment filtration and selective ion exchange treatment to remove Cesium and Cobalt.

The 3M membranes incorporate several classes of materials including commercial organic ion exchange materials, inorganic adsorbents, zeolyte structures, and elaborate macrocycles. The resulting membranes have effective separation efficiencies, radionuclide loading, fast flow rates and kinetics, and physical ruggedness. Materials that are resistant to high radiological fields (up to 2,000 megarad) may be used as the membrane matrix. The membrane is very densely packed with small (5 -25 μm), high-surface-area particles. The technology developer, 3M, expects that the rated flow rate of a production version of the cartridge will be 1.0 gpm. Higher flow rates can be accommodated by using multiple cartridges.

The membrane is fabricated into a cartridge which makes large volume chemical separations possible. The cartridge capacity varies depending on the sorbent type, the composition of the process stream, and the mass/volume of the process stream. Sorbent type must be selected specifically for the desired application, and may be affected by non-radioactive constituents in the stream. A high degree of particulate filtration (0.1 μm) must be provided upstream of the membrane cartridges to prevent plugging of the membrane cartridge.

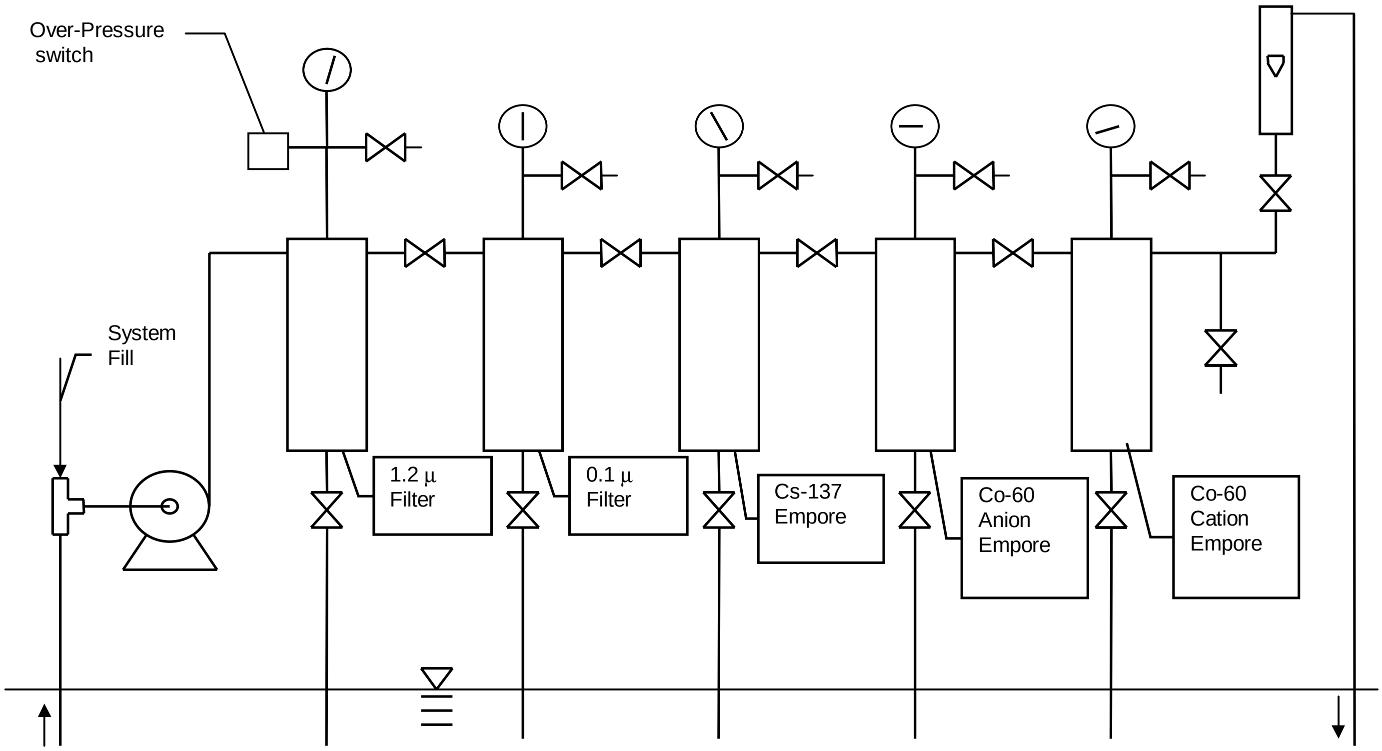


Figure 3. Membrane Filtration Demonstration Flow Schematic

Figure 4. Empore™ Membrane Separation Cartridge Inside Standard Filter Housing

The objective of the demonstration was to show the 3M membrane system was capable of removing trace amounts of Cs-137 and Co-60 from the storage pool water in E-wing of the CP-5 Reactor facility. Removal of cesium, strontium and technetium has been demonstrated previously at other sites. The system was comprised of several cartridge filters in series, including two prefilters to remove suspended particulate, and three “active” cartridges made of the 3M membrane embedded with specific ion exchange materials to remove Co-60 and Cs-137. The five cartridges were set up as follows:

1. 1.2 micron particulate filter (Filterite)
2. 0.1 micron particulate filter (Pall N66 Posidyne)
3. CoHex Exchange Cartridge (3M)
4. SLP Anion Exchange Cartridge (3M)
5. Diphonix Exchange Cartridge (3M)

Cs-137 and Co-60 content in the treated water was measured both upstream and downstream of each of five filter cartridges, with system performance evaluated as a function of time. This technology is not yet available commercially, although it has been previously field-tested. The results of the field tests, including the CP-5 test, will be used to scale-up the design for a full-scale system.

The performance of the system was quantified by collecting water samples, then counting the water samples in laboratories using long count times and equipment with minimum detectable activity (MDA) sensitivities able to detect the radioactivity level in the water after filtration. As a control, some samples were selected and sent to another on-site laboratory for more precise analysis.

The complete system included a pump, particulate filter housings, Empore™ membrane filter housings, and associated piping, valves, and controls. The system required minor assembly (including attaching piping and connections) before operations began. The final assembled system weighed approximately 100 pounds and had a footprint of about 14 ft by 3 ft by 3.5 ft high. The system required hookup to a 110 VAC, 20 amp electrical connection. No structural modifications to CP-5 were required.

Pool water was drawn from the pool by a small proportional pump, passed through the five filters, then returned to the pool. Pump and filter cartridges were positioned over the pool on grating, so that any leaks fell onto the grating and back into the pool. Although the filters are designed to handle a flow rate of 1 gpm, the pump drew water from the pool via flexible tubing at a rate of 0.3 - 0.5 gpm. The lower rate was due to the pump/tubing system limitations. The pool water flowed through the particulate and ion cartridges, then entered a flowmeter. The cleaned water was returned to the pool via flexible tube.

As precautions, the pump was plugged into a GFIC protected outlet by the pool, and a pressure switch was installed upstream of the first filter to shut off the pump if the pressure exceeded 50 psig (i.e., if the particulate loading on filter got too high or a shutoff valve was closed.) The electrical supply box was equipped with an over-current protection device. Each filter was equipped with a pressure gage for monitoring the system, and particulate filter cartridges were replaced to maintain system pressure below the pressure switch set point.

3M estimates a single set of cartridges could have been used to clean all the water in the CP-5 pool (~24,000 gallons), and that a single set of cartridges could process up to 160,000 gallons water, assuming adequate radiation shielding and particulate prefiltering are provided. Cartridges sets are determined based nuclides of concern. This estimate is also dependent on the amount of stable cesium in the water, and is based on tests performed at the N-Basin at Hanford. During that demonstration, cartridges were loaded with 100 grams of sorbent material to process the N-Basin water, which has a Cs-137 activity of 1.24E+06 pCi/L water.

SECTION 3

# PERFORMANCE

## Demonstration Plan

The purpose of this test was to demonstrate removal of trace amounts of Cs-137 and Co-60 from the storage pool water in E-wing of the CP-5 Reactor facility. The system was initially filled with laboratory water and checked for leaks, then switched to pool water. The assembly operated unattended at night, and except for brief periods to allow for particulate cartridge replacement, the system operated continuously for approximately 150 hours (from Sept.17 through Sept. 23, 1996). Demonstration activities were performed by CP-5 facility personnel. This consisted of the following:

- Health Physicist Technician - 1 - Part Time: Sample collection, filter changes, and equipment disassembly after demonstrations.
- Waste Management Mechanic - 1 - Full Time: Assigned by Field Engineer to provide assistance.
- Facility Technician - 1 - Part Time: Assisted in assembling system, making electrical connections, taking water samples, and changing filters.

Approximately 15 minutes training time was required to familiarize the facility personnel with the system.

The performance of the system was assessed through measurements of water samples taken from six sampling locations, including the input water and after each of the five cartridges. The samples were drawn from the system and placed directly into plastic sample bottles. Bottles were surveyed and transferred to an analytical laboratory for preliminary analysis. These samples were measured for Cs-137 and Co-60 content. Based on the preliminary analysis, certain sample sets underwent more rigorous analysis by another on-site laboratory.

Initial samples were drawn after operation was established to confirm proper system operation. Samples were then taken about every two hours during the first working day. After that, three sample sets were taken (one each during the morning, at midday, and at the end of the day) for each day the system was in operation. Due to time constraints, only critical samples were analyzed, as determined by ANL and 3M. During the demonstrations, the technology functioned independently, although some periodic surveillance was required. Particulate filter cartridges were changed three times during the demonstration for filter analysis.

At the conclusion of the demonstration, the water pump was shut off and the system was drained. Cartridge housings were drained and the cartridges removed. Cartridges were placed in plastic bags and placed in E-wing hood and allowed to air dry. After air drying, the five cartridges removed from the test rig at the end of the demonstration were transferred to the on-site laboratory for gamma counting. The other particulate cartridges were disposed of with other CP-5 radioactive wastes. The system was disassembled and openings were plugged, taped or bagged. The equipment was placed back into the shipping crate and stored at CP-5 in case any follow-up testing is conducted. Components without internal surfaces which could be surveyed were disposed of as regular scrap metal or waste. Components with internal surfaces which could not be accurately surveyed were disposed of as radioactive waste.

No water was disposed of during this demonstration (the cleaned water was returned to the pool). At the time of the demonstration, a relatively constant water level was maintained in the pool for the purpose of providing shielding for radioactive material stored in the bottom of the pool. There was no detectable increase in the airborne concentration of contaminants in the area.

Personnel exposure to hazards including noise, heat, electrical, radiological, etc. were approximately the same as or less than those that would be experienced performing the baseline technology (evaporation) using standard protective gear (personnel anticontamination clothing and splash protection). Cross-contamination of different systems did not pose a potential problem. From the time of arrival on site, 8 hours (16 person-hours) were required to prepare the system for the demonstration. Demonstration startup did not require additional regulatory review or notifications beyond standard operating procedures. The operation of the system was rated as the same or easier to operate than evaporation (with respect to operating instructions, trouble shooting, maintenance, etc.), and the technology did not negatively affect worker comfort.

The radiological waste consisted of 0.56 cu. ft. of filter cartridges. There was no generation of secondary waste. The internal surfaces of the system could not be surveyed, so the equipment was not decontaminated or released after use. Although the demonstration equipment could be used at another radiological facility, it was not designed as such and was disposed of as low level radiological waste.

Table 1 presents a summary of the radiological results of the samples analyzed. Samples were analyzed from 6 data sets (data sets (1) - (6)) collected on five days. Sample locations were as follows:

- V1 Inlet water
- V3 After 0.1 micron particulate filter (Pall N66 Posidyne)
- V4. After CoHex Exchange Cartridge (3M)
- V5 After SLP Anion Exchange Cartridge (3M)
- S1 Discharge water (After Diphonix Exchange Cartridge (3M))

Release criteria is 2 E-05 µCi/ml for Cs-137 in water (conservatively assumes 100% soluble) and 3 E-05 µCi/ml for Co-60 (conservatively assumes 100% insoluble). Throughout the demonstration the analyses of samples involved very low radiological concentrations and therefore required very long counting times per sample to determine the Co-60 and Cs-137 concentrations. Although the radionuclide content of the discharge water shows an increase over time (corresponding to a decrease in the decontamination factor of the system) this is not believed to be caused by the radiological loading of the filters. The two particulate filters were changed daily between September 17-19, and the resin filters were designed to filter out considerably more radioactivity than what was gathered. It is believed that the radionuclide concentration in the pool water was not homogeneous, and that the mixing of the water created by the Empore™ membrane separation system may have caused an increase in the radionuclide concentration of the inlet water, corresponding to an increase in the discharge water. Additionally, movement of the water may have stirred up material from the bottom of the pool, again corresponding to an increase in the radionuclide concentration of the inlet water. Inlet water was only analyzed at for 2 sample sets, which does not give an accurate profile of the inlet water concentration. Therefore, accurate decontamination factors for the system over time cannot be extrapolated. However, the Empore™ membrane separation system clearly shows a significant removal of radionuclides from the data collected during this demonstration, even at the very low concentrations used in this demo.

**Table 1. Sampling Results of the 3M Empore™ Filtration System**

| | (1) | | (2) | | (3) | | (4) | | (5) | | (6) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 17-Sep | | 18-Sep | | 19-Sep | | 20-Sep | | 23-Sep | | | |
| | 11:00 AM | | 11:30 AM | | 11:30 AM | | 8.30 AM | | 8:30 AM | | 3:30 PM | |
| | Cs-137 | Co-60 | Cs-137 | Co-60 | Cs-137 | Co-60 | Cs-137 | Co-60 | Cs-137 | Co-60 | Cs-137 | Co-60 |
| V1 | 5.60E-07 | 6.01E-08 | | | | | | | | | 6.17E-07 | 5.51E-08 |
| V3 | | | | | | | | | | | 5.01E-07 | 5.21E-08 |
| V4 | | | | | | | | | | | 2.47E-08 | 1.87E-08 |
| V5 | | | | | | | 2.23E-09 | 1.32E-08 | | | 1.85E-09 | 1.49E-08 |
| S1 | 1.07E-09 | 2.16E-09 | 3.35E-09 | 9.01E-09 | 7.81E-09 | 9.61E-09 | 1.07E-09 | 9.61E-09 | 1.07E-09 | 1.32E-08 | 1.07E-09 | 1.54E-08 |

NOTES:
(1) All concentrations are in µCi/ml
(2) MDA = 1.07E-09 µCi/ml for Cs-137

A final run of samples were performed the afternoon of the Sept. 23. Pool water was sampled after each filter, giving an overall view of the decontamination efficiency of the system and each filter. The overall decontamination factor through the system on this run was 575 for Cs-137 and 3.6 for Co-60. Figure 5 presents these results in graphical form.

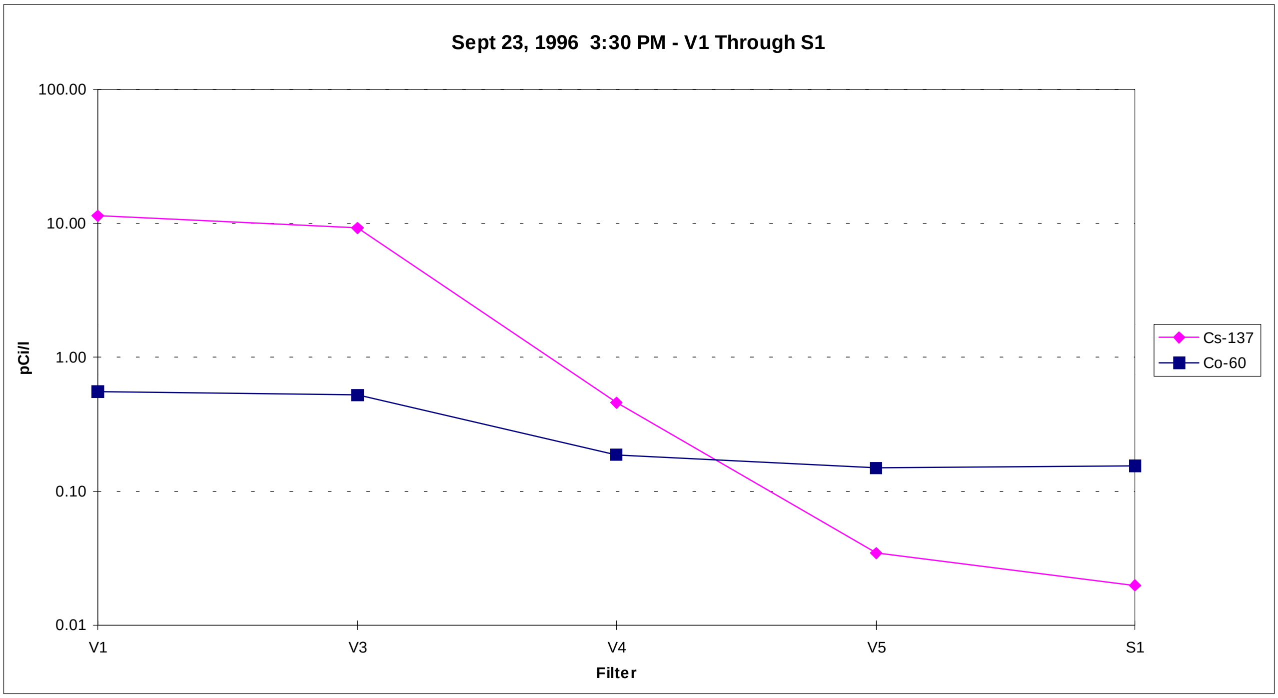

Figure 6. Sample results after each filter taken Sept. 23, 1996

SECTION 4

# TECHNOLOGY APPLICABILITY AND ALTERNATIVE TECHNOLOGIES

## Technology Applicability

The 3M membrane separation technology is applicable wherever an ion exchange process is required. This technology is designed to remove specific radionuclides in aqueous solution at high flow rates. 3M estimates flow rates of up to 1 gpm for a single cartridge, with higher flow rates for multiple cartridges. 3M has performed studies on the feasibility of up to 50 gpm. 3M studies have shown the fluid flow can be 10 to 100 times faster than standard column ion exchange processes while achieving equivalent or superior extraction efficiencies. Use of particles of the size used in the membrane technology would result in unacceptable back pressures in ion exchange columns. Channeling, or wall effects, can be a severe limitation for columns. The channeling phenomena is absent in membranes which increases the potential for using membranes at high flow rates. The membrane separation technology allows the use of a number of known, high-performance, chemical adsorbing powders, which previously could not be put into a useful engineered form because of their small particle size.

Additional advantages include:

- The sorbent material is used more efficiently than that they are in ion exchange columns
- Use of cartridges result in a smaller secondary waste stream
- Cartridge sorbents can be selected for the specific contaminants in the water

The major limitation of this technology is the high radionuclide loading capability of the filters, which could exceed low level radioactive waste limits if not properly monitored.

## Competing Technologies

The baseline technologies with which the Empore™ membrane separation technology competes are evaporation systems located on-site and mobile and ion exchange columns. Both of these are established technologies with predictable results (see Appendix C for details about procedures and equipment used in the evaporation process).

## Patents/Commercialization Sponsor

The technology is being developed and marketed by 3M Company. 3M has several patents relating to separation technology materials and/or methods. These include: US 4, 153, 661; US 5,071, 610; US 5,147,539; US 5, 207,916; US 5,618,438; US 5,616,438; US5,616,407; US5,328,758; and US 5,115,779.

SECTION 5

# COST

## Introduction

This cost analysis compares the relative costs of the innovative and baseline technology and presents information which will assist D&D planners in decisions about use of the innovative technology in future D&D work. This analysis strives to develop realistic estimates that represent decontamination and decommissioning (D&D) work within the DOE complex. However, this is a limited representation of actual cost, as the analysis uses only data observed during the demonstration. Some of the observed costs will include refinements to make the estimates more realistic (such as elimination of cost factors which are not part of normal work but included in the demonstration to evaluate equipment performance). This is done only when they will not distort the fundamental elements of the observed data (e.g., do not change the productivity rate, quantities, and work elements, etc.) and eliminates only those activities which are atypical of normal D&D work. The Empore™ membrane separation technology Data Report (ANL, 1997) provides additional information and is available upon request from the Argonne National Laboratory (ANL).

## Methodology

This cost analysis compares the technology for an 0.50 gpm extraction membrane filtration system in a standard cartridge format using various ion exchange materials (absorbents), against two baseline technologies of shipping the water in portable tanks to an on-site evaporator facility for treatment and using mobile treatment service provided by a vendor. The Empore™ membrane separation technology was demonstrated at ANL under controlled conditions which facilitated observation of the work procedures and typical duration of work activities. The baseline survey was not demonstrated concurrently. The baseline cost was developed from an historically based estimate and data provided by ANL. Site personnel at ANL also provided Labor, equipment, and production rates.

Since the baseline costs are not based on data observed under controlled conditions, additional efforts are applied in setting up the baseline cost analysis to assure reasonable production rates and crew costs. Specifically, a team consisting of members from the Strategic Alliance and the U.S. Army Corps of Engineers (USACE) reviewed the estimate assumptions to ensure a fair comparison.

The selected basic activities being analyzed come from the Hazardous, Toxic, Radioactive Waste Remedial Action Work Breakdown Structure and Data Dictionary (HTRW RA WBS), USACE, 1996. The HTRW RA WBS, developed by an interagency group, is used in this analysis to provide consistency with the established national standards.

Some costs are omitted from this analysis to make it easier to understand and to facilitate comparison with costs for the individual site. The ANL indirect expense rates for common support and materials are omitted from this analysis. Overhead and General and Administrative (G&A) rates for each DOE site vary in magnitude and in the way they are applied. However, an amount of 9.3 % has been added to the cost for procurement (standard rate for ANL). Decision-makers seeking site specific costs can apply their site's rates to this analysis with out having to first back-out the rates used at ANL. The impact resulting from this omission is judged to be minor as overhead would be applied to both the innovative and baseline technology costs. Engineering, quality assurance, administrative costs and taxes on services and materials are also omitted from this analysis for the same reasons.

The standard labor rates established by ANL for estimating D&D work are used in this analysis for the portions of the work performed by ANL crafts. Costs for site owned equipment, such as trucks for transport or Health Physics Technician (HPT) radiological survey equipment, are based upon an hourly rate for Government ownership that is computed using OMB Circular No. A-94. Quoted rates for the vendor's costs are used in this analysis and include the vendor's G&A overhead and other mark ups. Additionally, the analysis uses an eight hour day and a five day week for computing labor cost even though the filtration system was operating around the clock (continuously) .

## Cost Data

Currently, the Empore™ membrane separation technology is available on a project by project basis as either the stand-alone cartridge or as a custom designed system. The vendor is presently determining the best way to meet the needs of the industry. At this time, a site would assemble the piping, valves, etc. to construct the Empore™ system and then purchase the filters and cartridges from the vendor. Labor and materials for a five gpm system is estimated to cost approximately $15,000 and for a 50 gpm system approximately $25,000.

**Table 2. Innovative Technology Acquisition Costs**

| ACQUISITION OPTION | ITEM | COST |
|---|---|---|
| Vendor Provided Service's | Not currently available, but being considered by the vendor. | |
| Cartridge and Filter Purchase | 1.2 micron filter Pall HCD<br>0.1 micron filter pall N 66 Posidyne<br>CoHex Exchange Cartridge (3 M ) | $68.65<br>$210.17<br>$2,000.00 |

The filters were replaced at approximately 1500 gallon intervals. This replacement rate will vary depending upon site specific conditions. The CoHex cartridge was not replaced during the demonstration where 4500 gallons of water were processed, but based on computations by 3M, the cartridge would have adequate capacity to treat the entire storage basin (24,000 gallons). The cartridge costs will vary depending upon the contaminant and the size of the order. The cartridge price shown is for an order of ten cartridges.

**Table 3. Summary of Unit Costs & Production Rates**

| Empore™ | | Baseline - Evaporation | | Baseline - Mobile Treatment | |
|---|---|---|---|---|---|
| Unit Cost $/gallon | Production Rate gallons/day | Unit Cost $/gallon | Production Rate gallons/day | Unit Cost $/gallon | Production Rate gallons/day |
| 1.71 | 650 | 3.71 | 700 | 2.51 | 10,000 - 13,000 |

The unit costs and production rates shown do not include mobilization or demobilization (computed from Tables C-1, C-2, and C-3 using the subtotals of the treatment, disposal and procurement divided by 24,000 gallons).

## Summary of Cost Variable Conditions

The demonstration for the Empore™ membrane separation technology was performed at CP-5 processing 4500 gallons of water. However, the estimate is based on a processing the volume of the fuel storage basin (24,000 gallons). The estimate is based on extrapolated quantities so that the costs are not unduly dominated by mobilization and demobilization costs (size extrapolated to a size of job typical of D&D projects). The working conditions and quantity of materials to be processed for an individual job directly affect the manner in which D&D work is performed and, as a result, the costs for an individual job are somewhat unique. The innovative and baseline technology estimates presented in this analysis are based upon a specific set of conditions or work practices found at CP-5, and are presented in Table 4. This table is intended to help the technology user identify work differences that can result in cost differences.

**Table 4. Summary of Cost Variable Conditions**

| Cost Variable | Empore™ Membrane Separation Technology | Baseline | |
|---|---|---|---|
| Scope of Work | | | |
| Quantity and Type | 24,000 gal of Radioactive liquid waste. | 24,000 gal of Radioactive liquid waste. | |
| Location | CP-5 Reactor Facility Storage pool | CP-5 Reactor Facility Storage pool | |
| Nature of Work | Untreated water has a pH of 7.8 and 1000 -1500 conductivity, hardness 100 ppm (mostly calcium). Initial concentrations are 0.6 pCi/l for Cs-137 and 0.2 pCi/l for Co-60. Both are treated to below 0.02 pCi/ml. The estimate assumes that the treated effluent is discharged to an adjacent drain. | <u>Evaporation</u><br>Evaporation/concentration of basin water. | <u>Mobile Treatment</u><br>Filtration and selective ion exchange treatment to remove Cesium and Cobalt. |
| Work Environment | | | |
| Worker Protection | Anti-contamination (splash protection) TYVEK coveralls with hood and booties, Face shield w/ respirator, and gloves. | Anti-contamination (splash protection) TYVEK coveralls with hood and booties, Face shield w/ respirator, and gloves. | |
| Level of Contamination | Classified as a contaminated area and a radiation area | Classified as a contaminated area and a radiation area | |
| Work Performance | | | |
| Acquisition Means | Cartridge and filter purchased from vendor, construction and operation of system by site personnel. | <u>Evaporation</u><br>Site personnel with site owned equipment | <u>Mobile Treatment</u><br>Vendor provided service. |
| Production Rates | Membrane cartridge separation performed at 0.5 gallons per minute (gpm). This rate can be increased to as much as 50 gpm through the redesign of the filter system. | Evaporation system will process 700 gallons per day (gpd) | 10 gpm |
| Equipment & Crew | One HPT part time and one full time technician for operation with a waste management mechanics for setup, and filter change. | One HPT, two D&D workers and, Two truck operators full time. | Vendor personnel. |
| Work Process Steps | 1. Sample & analysis<br>2. Transport equipment from storage to work location<br>3. Instruction for operators (one time)<br>4. Setup and Check out System<br>5. Start treatment process<br>6. Obtain 2 samples per day<br>7. Change Filters @ 1500 gal intervals<br>8. Decontaminate & pack for transport<br>9. Transport to storage | 1. Sample & analysis<br>2. Prepare pumps and hoses<br>3. Transport to work area<br>4. Setup pumps and piping<br>5. Transfer water to portable tanks<br>6. Transport water to evaporator<br>7. Decontaminate and pack<br>8. Transport to storage | 1. Sample and analysis<br>2. Transport to site<br>3. Survey prior to coming on site<br>4. Site orientation<br>5. Set up<br>6. Start treatment<br>7. Obtain 2 samples/day<br>8. Decontaminate & pack for transport<br>9. Transport |
| | | | |

## Potential Savings and Cost Conclusions

The Empore$^{TM}$ membrane separation technology is estimated to save approximately 50% over the evaporation baseline and 30% over the mobile treatment service for treating the water in the fuel storage basin. The costs are summarized in the Figure 5:

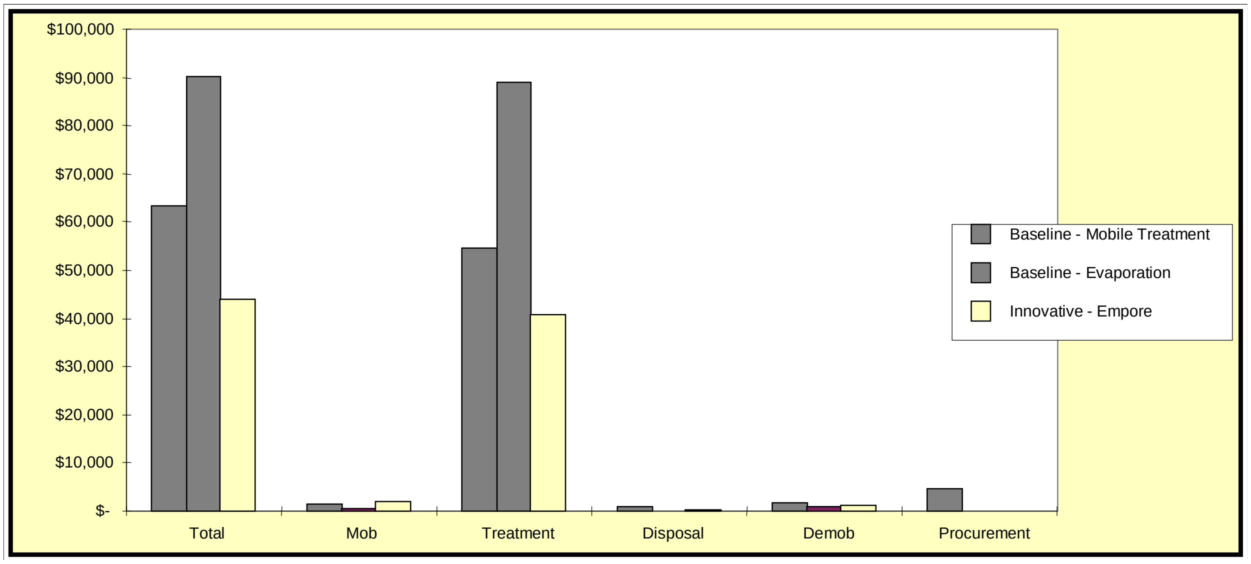


**Figure 5. Cost Comparison**

For the conditions of this demonstration, the Empore$^{TM}$ membrane separation technology is less expensive than the baseline technologies. The Empore$^{TM}$ system advantage over the evaporator is less labor cost, principally the intensive effort to transport to the evaporator facility. The comparison to the mobile treatment baseline is less clear because of the lack of breakdown in the vendor's quotation for bringing a mobile treatment system on site. The procurement cost is a major cost for the mobile treatment baseline. The Empore$^{TM}$ membrane separation technology costs are principally labor and may vary with local site work procedures (for example 24 hour attendance of the equipment may be required at some sites or two technicians may be required rather than one).

This estimate assumes that the treated effluent from the Empore$^{TM}$ is discharged to a nearby drain, but the estimate does not include costs for obtaining the discharge permit. The number of samples required for compliance with a discharge permit is not known. This estimate assumed two samples per day, but the actual requirements may vary with the nature of the contamination and regulatory climate.

SECTION 6

# REGULATORY/POLICY ISSUES

## Regulatory Considerations

The regulatory/permitting issues related to the use of the 3M Empore™ membrane separation technology at the ANL CP-5 Research Reactor consisted of the following safety and health regulations:

- Occupational Safety and Health Administration (OSHA) 29 CFR 1926
  - —1926.300 to 1926.307 Tools-Hand and Power
  - —1926.400 to 1926.449 Electrical - Definitions
  - —1926.28 Personal Protective Equipment
  - —1926.102 Eye and Face Protection
  - —1926.103 Respiratory Protection

- OSHA 29 CFR 1910
  - —1910.301 to 1910.399 Electrical - Definitions
  - —1910.132 General Requirements (Personal Protective Equipment)
  - —1910.133 Eye and Face Protection
  - —1910.147 The Control of Hazardous Energy (Lockout/Tagout)

These regulations apply to the hazards associated with the 3M Empore™ membrane separation technology (based on a Hazards Analysis performed as part of the LSDP demonstration), which include possible exposure to radiological materials (external, internal, and possible tritium), pressurized liquids, electrical sources, air emissions, and radioactive waste.

The waste form requirements/criteria specified by disposal facilities used by ANL include:

- *Hanford Site Solid Waste Acceptance Criteria*: WHC-EP-0063-4
- *Barnwell Waste Management Facility Site Disposal Criteria*: S20-AD-010
- *Waste Acceptance Criteria for the Waste Isolation Pilot Plant*: WIPP-DOE-069

These waste form requirements/criteria may require the stabilization or immobilization of final waste streams due to their powdery consistency. All low level waste must be packaged in accordance with the applicable Site- specific requirements.

## Safety, Risks, Benefits, and Community Reaction

With respect to safety issues, the Empore™ system involves the same considerations as those involved in most radioactive liquid treatment technologies. These considerations include the potential for airborne radioactivity, splash dangers, and electrical shock from the system. These dangers are typical of what is routinely encountered in an industrial environment.

The major benefit of the Empore™ membrane separation technology is that it allows the removal of radioactive contaminants at increased flow rates when compared to ion exchange or evaporators, while concentrating the contaminants in a minimum of secondary waste. The full system is projected to have a lower capital cost and smaller footprint than conventional technology. The small footprint and versatility of design may help facilitate retrofitting at existing installations.

SECTION 7

# LESSONS LEARNED

## Implementation Considerations

The Empore™ membrane separation technology is currently undergoing research to upscale the demonstration system from 0.5 gpm to as high as 50 gpm. Primary considerations include the performance of the filters under these conditions, and the radiological loading on the filters.

## Technology Limitations and Needs for Future Development

The used cartridges may have unacceptably high radiation levels if the membranes become saturated with radiological particulates. As part of the development of this technology, the Empore™ membrane separation technology would benefit if controls were implemented to ensure overloading of radiological material does not occur.

## Technology Selection Considerations

Once a production level system is developed, the Empore™ membrane separation technology will be applicable to any large nuclear site which requires the treatment of radionuclide-containing waste in aqueous solution. This includes nuclear weapons production sites, research facilities, and commercial nuclear sites. The particular sorbants used and the configuration of the membranes will be site-specific; however, Empore™ membrane separation technology can be tailored to remove most radionuclides down to specific detection levels. This is applicable to all applications where evaporators or ion exchange columns are required.

The limiting factor may be developing a system with the flow capacity to handle large volumes of liquid in limited time frames.

# Appendix A

## REFERENCES


(1) Bray, L. A.., G. N. Brown (PNNL); L. C. Lewis, C. W. Lundholm (INEL); D. R. Anderson, T. M. Kafka, L. R. White (3M), R. L. Bruening, R. H. Decker (IBC). "Web Technology in the Separation of Strontium and Cesium from INEL-ICPP Radioactive Acidic Waste (WM-185)." Report PNNL-10283, 1995 Pacific Northwest Laboratory, Richland, Washington.

(2) Dinsmore, E. F., G. Smith, (West Valley Nuclear Co.), L. A. Bray, G. N. Brown, (PNNL), K. C. Carlson, T. M. Kafka, D. C. Seely, L. R. White, (3M). "Removal of Specific Radionuclides from Process Streams at the West Valley Demonstration Project using 3M Separation Technology." Topical Report to Efficient Separations and Processing Crosscutting Program, May 1996. 3M New Products Department, St. Paul, MN.

(3) Herbst, R. S., K. N. Brewer, T. A. Todd, (Lockheed Idaho Technologies Company), L. A. Bray, (PNNL) T. M. Kafka, L. R. White, (3M). "Decommissioning of TAN Injection Well Water Using 3M WebTechnology." Report, November 1995, INEL-95\0589, Lockheed Idaho Technologies Company, Idaho Falls, ID.

(4) Kafka, T. M., L. R. White, (3M), A. G. Dada, (Bechrel Hanford), G. N. Brown, (PNNL), Richland, W. A. "Removal of Radionuclides at the Hanford 105-N Basin Using 3M Separation Technology." American Nuclear Society Conference on Decommissioning, Decontamination and Reutilization of Commercial and Government Facilities, Knoxville, TN, September 7-12, 1997.

(5) AIF, 1986 Guidelines for Producing Commercial Nuclear Power Plant Decommissioning Cost Estimates, May 1986, National Environmental Studies Project of the Atomic Industrial Forum, Inc., 7101 Wisconsin Avenue, Bethesda, MD 20814-4891.

(6) Hazardous, Toxic, Radioactive Waste Remedial Action Work Breakdown Structure and Data Dictionary. 1996, Headquarters United States Army Corps of Engineers, 20 Massachusetts Avenue, N.W., Washington, D.C., 20314-1000.

## Appendix B

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ACE | Activity Cost Estimate (Sheets) |
| ANL | Argonne National Laboratory |
| CF | Cubic Feet (Foot) |
| CFM | Cubic Feet Per Minute |
| COE | Corps Of Engineers |
| CP-5 | Chicago Pile 5 Research Reactor Facility |
| D&D | Decontamination And Decommissioning |
| DDFA | D&D Focus Area |
| Decon | Decontamination |
| Demo | Demonstration |
| Demob | Demobilization |
| DOE | Department of Energy |
| DOE-CH | DOE- Chicago |
| DOE-RL | DOE- Richland (WA) |
| ER | Environmental Restoration |
| ESH | Environment, Safety and Health |
| FCCM | Facilities Capital Cost Of Money |
| FETC | Federal Energy Technology Center |
| gpd | Gallons per day |
| gpm | Gallons per minute |
| G&A | General and Administrative Markup Cost |
| GFCI | Ground Fault Circuit Interrupter |
| H&S | Health and Safety |
| HP | Health Physics |
| HPT | Health Physics Technician |
| Hr | Hour |
| HTRW | Hazardous, Toxic, Radioactive Waste |
| LF | Lineal Feet (Foot) |
| LLW | Low Level Waste |
| LS | Lump Sum |
| LSDP | Large Scale Demonstration Project |
| MDA | Minimum Detectable Activity |
| Min | Minute |
| Mob | Mobilization |
| NESP | National Environmental Studies Project |
| OT | Overtime |
| PC | Personal Computer |
| PCs | Protective Clothing |
| pCi/ml | picocuries per milliliter |
| PLF | Productivity Loss Factor |
| PPE | Personal Protective Equipment |
| Qty (Qnty) | Quantity |
| RA | Remedial Action |
| SF | Square Feet (Foot) |
| Tech | Technician |
| UCF | Unit Cost Factor |
| UOM | Unit Of Measure |
| USACE | U.S. Army Corps Of Engineers |
| WBS | Work Breakdown Structure |
| WPI | Waste Policy Institute |

# Appendix C

## TECHNOLOGY COST COMPARISON

This Appendix contains definitions of cost elements, descriptions of assumptions, and computations of unit costs that are used in the cost analysis.

## Innovative Technology - Empore$^{TM}$ Membrane Separation Technology

**MOBILIZATION (WBS 331.01)**

*Lab Analysis of Water:* Sampling and analysis performed to determine the type of cartridges required for treatment.

*Transport Equipment:* Transport Empore$^{TM}$ membrane separation equipment from Storage at Argonne National Laboratory to tank area.

*Set Up Equipment:* Equipment and filter's are unpacked, surveyed for damage, and prepared for use.

*Training of Operators:* The operators are familiarized with the Empore$^{TM}$ equipment.

**TREATMENT BY ION EXCHANGE (WBS 331.12.05)**

*Pre-Operational Check:* System is run to check for leaks and proper performance.

*System Operation:* The processing of the contaminated water through the filter system, taking required samples, changing filter's as required and then discharging the filtered water into a retention tank for future discharge into the treated sanitary drain system. The technician is present at all times during the week day (not present at night or weekends). The waste management mechanic is present for sampling events and for changes of the filters and cartridges.

*PPE:* Personal protective equipment for the innovative technology was worn when samples were collected and when filters were replaced. Only two pair were used during the demonstration, because the same sets were re-warn for each sample event.

**Table B-1. Innovative Technology PPE**

| Equipment | Quantity in Box | Cost Per Box | Cost Each | No. of Reuses | Cost Each Time Used | No. Used Per Day | Cost Per Day |
|---|---|---|---|---|---|---|---|
| Respirator | | | 1,933 | 200 | 10 | 3 | 30.00 |
| Resp. Cartridges | | | 9.25 | 1 | 9.25 | 3 | 27.75 |
| Booties (w/Tyvek suit) | | | | | | | |
| Tyvek 7A-18100 (w/ Hood) | 24 | 236.40 | 9.85 | 1 | 9.85 | 3 | 29.55 |
| Gloves (inner) | 12 | 2.00 | 0.17 | 1 | 0.17 | 3 | 0.51 |
| Gloves (outer ) | | | 7.45 | 10 | 0.75 | 3 | 2.25 |
| **Total** | | | | | | | 46.33 |

**DEMOBILIZATION (WBS 331.21)**

*Decontaminate Equipment and Prepare for Transport: Empore™* membrane separation technology equipment is surveyed for contamination and packed for transport.

*Transport Equipment: Transport* back to storage. Same equipment and effort as mobilization.

**WASTE DISPOSAL (WBS 331.18)**

Waste generated from the decontamination operation and from the disposal of the filters and cartridges are included in this activity.

The assumptions for projecting the demonstration costs for the Empore™ filtration system to reflect a commercial cost are summarized as follows:

- The demonstration used one radiological and elemental analysis @ $482.70 each and one total carbon and organic carbon analysis @ $429.70 each.
- Transportation costs assumed to include two riggers, one truck with driver and a fork lift with operator. Rates for equipment from Dataquest, 1996.
- Equipment set up crew consists of Two Waste Management mechanics for 6 hours each and an Electrical Technician for two hours.
- The demonstration provided approximately 15 minutes for the required training.
- The demonstration required approximately two hours for the pre-operational check.
- System Operation labor for the technician will be performed 8 hours per day, 5 days a week. Processing, will be done on a continuous basis (24 hours per day) with the exception of the 1.5 hours down time each day for the sampling and the estimated sixteen changes of filter sets at 30 min. each (total eight hours). At a rate of 0.5 gpm and with the 1.5 hour per day down time, the duration is 37 days. Filters were observed to be changed at approximate intervals of 1500 gallons. The demonstration was performed with three different cartridges, but future deployments would only use one (type) of cartridge, COHEX. Computations by 3M indicate that a single cartridge could have processed the 24,000 gallons. The price of $2,000 is based on a purchase of ten cartridges.
- Assume that all waste is low level waste. Each filter and cartridge is approximately 3”X3”X12” = .0625 ft3. For 24,000 gallons there would be 32 filters used and 1 cartridges = 33 . Volume = 33 X 0.0625 ft3 = 2.1 ft3. Assume one additional ft3 for waste generated by the decontamination for a total of 3.1 ft3.

**The costs for the innovative technology are shown in Table B-2.**

Table B-2. Cost For Innovative Technology

| Work Breakdown Structure (WBS) | Unit Cost (UC) Labor HRS | Labor Rate | Equipment HRS | Equipment Rate | Other | Total UC | Total Quantity (TQ) | Unit of Measure | Total Cost (TC) note | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| **MOBILIZATION WBS 331.01** | | | | | | | | | | |
| Lab Analysis of Water | 0.00 | $ - | 0.00 | $ - | $ 912 | $ 912 | 1 | Each | $ 912 | Determine cartridge required |
| Transport Equipment | 2 | $146.9 | 2.00 | $ 32.51 | $ - | $ 359 | 1 | Trip | $ 359 | Truck, forklift, teamster, operator, & 2 decon workers for 2 hour |
| Set-Up Equipment | | | 6.00 | $ 4.92 | | $ 30 | 1 | Each | $ 30 | Includes standby of Empore™ at $ 4.92/hour |
| Mechanic (2) | 12 | $49.67 | | | | $ 596 | 1 | Each | $ 596 | |
| Electrician | 2 | $49.67 | | | | $ 99 | 1 | Each | $ 99 | |
| Training of Operators (2) | 0.5 | $49.67 | | | | $ 25 | 1 | Each | $ 25 | One Time Cost |
| | | | | | | | | **Subtotal** | **$ 2,021** | |
| **Treatment Ion Exchange 331.12.05** | | | | | | | | | | |
| Pre-Operational Check | 0.00 | $ - | 2.00 | $ 4.92 | $ - | $ 10 | 1 | Each | $ 10 | |
| Mechanics | 2.00 | $49.67 | 0.00 | $ - | $ - | $ 99 | 1 | Each | $ 99 | Waste Mngt. Mech. @ $49.67 |
| Electrician | 2.00 | $49.67 | 0.00 | $ - | $ - | $ 99 | 1 | Each | $ 99 | |
| Operation of Empore™ | | | | | | | | | | |
| Technician | 296.00 | 33.60 | 296 | $ 4.92 | | $ 11,402 | 1 | Each | $ 11,402 | 37 days @ 8 hours/day |
| Filter Cartridges (2) | | | | | $ 279 | $ 279 | 16 | Sets | $ 4,461 | Two approx. every 1500 gal. |
| Ion Exchange Cart. | | | | | $ 2,000 | $ 2,000 | 1 | Each | $ 2,000 | |
| Sampling & Testing | 0.00 | $ - | 0.00 | $ - | $ - | $ 250 | 74 | Sample | $ 18,500 | 2 samples/ day for 37 days |
| Mechanics | 0.50 | $49.67 | 0.00 | $ - | $ - | $ 25 | 74 | Sample | $ 1,838 | |
| H P Technician | 0.50 | $56.00 | 0.00 | $ - | $ - | $ 28 | 74 | Sample | $ 2,072 | |
| Change filters | | | | | | | | | | 16 filter sets |
| Mechanics | 0.50 | $49.67 | 0.00 | $ - | $ - | $ 25 | 16 | Each | $ 397 | |
| H P Technician | 0.50 | $56.00 | 0.00 | $ - | $ - | $ 28 | 16 | Each | $ 448 | |
| | 0.00 | $ - | 0.00 | $ - | $ - | $ - | | | $ - | |
| Protective Clothing (PCs) | 0.00 | $ - | 0.00 | $ - | $ 9.85 | $ 46 | 2 | Each | $ 93 | Splash protective suit |
| | | | | | | | | **Subtotal** | **$ 41,419** | |
| **DEMOBILIZATION WBS 331.21** | | | | | | | | | | |
| Decon & Prep for Trans | 0.00 | $ - | 8.00 | $ 4.92 | $ - | $ 39 | 1 | Each | $ 39 | Includes standby for Empore™ |
| Mechanics | 8.00 | $49.67 | 0.00 | $ - | $ - | $ 397 | 1 | Each | $ 397 | |
| H P Technician | 4.00 | $56.00 | 0.00 | $ - | $ - | $ 224 | 1 | Each | $ 224 | |
| Transport Equipment | 2.00 | $146.9 | 2.00 | $ 32.51 | | $ 359 | 1 | Each | $ 359 | Same as the Mobilization |
| | | | | | | | | **Subtotal** | **$ 1,020** | |
| **Waste Disposal WBS 331.18** | | | | | | | | | | |
| Cartridge Disposal | | | | | $ 53 | $ 53 | 3.1 | ft3 | $ 164 | Low Level Waste Disposal |
| | | | | | | | | **Subtotal** | **$ 164** | |

Note: TC = UC * TQ **INNOVATIVE TOTAL: $44,623**

## Base Line Technology - On-Site Evaporation

**MOBILIZATION (WBS 331.01)**

*Load and Transport Equipment*: Transport pumps, hose and portable tanks to pool site from storage area.

*Set Up Pumps and Hoses*: Equipment (pumps and hose) are taken from crates or pallets , and prepared for use.

**D&D (WBS 331.01)**

*Pump from Basin to Tank*: Pump water from basin to the tanks for transport.

*Transport to Evaporator:* Hauling the water to the evaporator in 850 gallon tanks mounted on a truck.

*Evaporator Treatment of Water: This* activity includes the amortized cost of the evaporator facility and the operation costs.

*PPE*: Protective clothing is assumed as shown below:

**Table B-3. Baseline Technology PPE**

| Equipment | Quantity in Box | Cost Per Box | Cost Each | No. of Reuses | Cost Each Time Used | No. Used Per Day | Cost Per Day |
|---|---|---|---|---|---|---|---|
| Respirator | | | 1,933 | 200 | 10 | 3 | 30.00 |
| Resp. Cartridges | | | 9.25 | 1 | 9.25 | 3 | 27.75 |
| Booties (w/Tyvek suit) | | | | | | | |
| Tyvek 7A-18100 (w/ Hood) | 24 | 236.40 | 9.85 | 1 | 9.85 | 3 | 29.55 |
| Gloves (inner) | 12 | 2.00 | 0.17 | 1 | 0.17 | 3 | 0.51 |
| Gloves (outer ) | | | 7.45 | 10 | 0.75 | 3 | 2.25 |
| **Total** | | | | | | | 46.33 |

**DEMOBILIZATION (WBS 331.21)**

*Decontaminate Equipment*: Pumps, hoses etc. is surveyed for contamination and prepared for transport.

*Transport Equipment*: Transport back to storage. Same equipment and effort as mobilization.

**WASTE DISPOSAL (WBS 331.18)**

Waste generated from the decontamination operation is included in this activity.

The assumptions for projecting the system costs for the Base Line technology (evaporation) are summarized as follows:

- Transport of equipment is assumed to include two labor’s, one truck with driver and a fork lift with operator.
- Set up crew consists of Two D&D workers and an Electrical Technician.

- Assume that the duration for pumping water from the basin to the tanks is constrained by the duration for transport (i.e. the crew waits until the truck empties its load and returns). Crew is assumed to be two D&D workers and a foremen for 1/4 of the time. Rate for pump based on rental rate from Dataqest, 1997.

- Assume 5 trips to the evaporator per day. The total transport of 24, 000 gal. requires 45 hours. Assume a crew of two teamsters and one HPT.

- Using conservative assumptions about the evaporator construction cost ($2,000,000), annual repairs (1/2 FTE) and operation (2 FTEs), an hourly rate of $101.75 was estimated. Although the actual construction price is unknown, it is unlikely that the facility cost less than $2,000,000. Consequently, the hourly rate for the facility is likely to be more than the $101.75 used in this analysis. For 24 hour operation of the facility, the daily cost would be 24 hours/day X $101.75 / hour = $2,442 / day. A unit cost based on the through put of 700 gallon per day is $2,442 per day / 700 gallon per day = $3.49 / gallon.

- Assume that one ft3 of waste is generated during decontamination.

The costs for the baseline technology are summarized in Table B-4:

**Table B-4. Baseline Technology Costs**

| Work Breakdown Structure (WBS) | Unit Cost (UC) Labor HRS | Labor Rate | Equipment HRS | Equipment Rate | Other | Total UC | Total Quantity (TQ) | Unit of Measure | Total Cost (TC) note | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| **MOBILIZATION WBS 331.01** | | | | | | | | | | |
| Load and Transport | 2.00 | $ 147 | 2.00 | $ 32.51 | $ - | $ 359 | 1 | Each | $ 359 | Truck, forklift, teamster, operator, & 2 decon workers for 2 hour |
| Set Up Pumps & Hose | | | 1.00 | $ 1.43 | | $ 1.43 | 1 | Each | $ 1.43 | Pumps and Hoses |
| D&D Worker (2) | 2.00 | $33.60 | | | | $ 67 | 1 | Each | $ 67 | |
| Electrician | 1.00 | $49.67 | | | | $ 50 | 1 | Each | $ 50 | |
| | | | | | | | | **Subtotal** | **$ 477** | |
| **Treatment - Evap. WBS 331.13.06** | | | | | | | | | | |
| Pump from Basin to Tank | | | | | | | | | | Duration Controlled by Trans. |
| D&D Worker (2.25) | 101.25 | $33.60 | 45.00 | $ 1.43 | | $ 3,466 | 1 | Each | $ 3,466 | Includes elec. pump rental |
| Trans. to Evaporator | | | | $ - | $ - | $ - | | | $ - | 5 trips/day @ 850gal/trip |
| Teamsters (2) | 90.00 | $49.67 | 45.00 | $ 17.52 | | $ 5,259 | 1 | Each | $ 5,259 | Includes truck rental |
| Health Physics Tech. | 45.00 | $56.00 | 0.00 | $ - | $ - | $ 2,520 | 1 | Each | $ 2,520 | |
| Evap. Treatment of Water | | | | $ - | $ 3.49 | $ 3.49 | 24,000 | Gallons | $ 83,760 | Treat. rate = 700 gal/day |
| Operator (2) | 550.00 | $49.67 | 0.00 | $ - | $ - | $ 27,319 | 1 | Each | $ 27,319 | |
| Protective Clothing (PCs) | 0.00 | $ - | 0.00 | $ - | $ 46 | $ 46 | 18 | Man Days | $ 834 | 3 persons for 6 days @ 46.33/day |
| | | | | | | | | **Subtotal** | **$ 123,157** | |
| **DEMOBILIZATION WBS 331.21** | | | | | | | | | | |
| Decontaminate Equip. | 0.00 | $ - | 0.00 | $ - | $ - | $ - | | | $ - | |
| Health Physics Tech. | 8.00 | $56.00 | 0.00 | $ - | $ - | $ 448 | 1 | Each | $ 448 | |
| Transport Equipment | 2.00 | $ 147 | 2.00 | $ 32.51 | $ - | $ 359 | 1 | Each | $ 359 | Same as mobilization |
| | | | | | | | | **Subtotal** | **$ 807** | |
| **WASTE DISPOSAL – WBS 331.18** | | | | | | | | | | |
| Waste Disposal | | | | | $ 52.78 | $ 53 | 1 | ft3 | $ 53 | Waste from decon |
| | | | | | | | | **Subtotal** | **$ 53** | |

Note: TC = UC * TQ **BASELINE TOTAL: $ 124,494**

**MOBILIZATION (WBS 331.01)**

Mobilization costs for the vendor are included in a quote provided by the vendor (quote is for a lump sum with out breaking out the cost for mobilization separately). Site support required for mobilizing the vendor is included in the estimate and includes Health Physics support for survey of the equipment when it arrives on site, site orientation for the vendor personnel (not broken out separately in the quote), and assistance with set up of the equipment

**TREATMENT (WBS 331.12.05)**

Costs for treating 24,000 gallons was provided by a quote from a vendor. In addition, this estimate includes costs for site support of the treatment operation (escort/Health Physics Technician full time and sampling and analysis of the effluent). The vendor assumed a total time on site of two weeks (includes mobilization, demobilization, orientation, and set up) and with a through put of 10 gallons per minute, the treatment should be last approximately four days.

**DEMOBILIZATION (WBS 331.21)**

This effort provides Health Physics Technician and D&D worker support for decontamination of the vendor's equipment.

**WASTE DISPOSAL (WBS 331.18)**

The vendor estimated approximately one drum of waste would be generated by the treatment operation.

The costs for the baseline technology are summarized in Table B-5:

## Table B-5. Cost Summary for Baseline - Mobile Treatment

| Work Breakdown Structure (WBS) | Unit Cost (UC) Labor HRS | Labor Rate | Equipment HRS | Equipment Rate | Other | Total UC | Total Quantity (TQ) | Unit of Measure | Total Cost (TC) note | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| **MOBILIZATION WBS 331.01** | | | | | | | | | | |
| Lab Analysis of Water | 0.00 | $ - | 0.00 | $ - | $ 912 | $ 912 | 1 | Each | $ 912 | Determine cartridge required |
| Transportation | | | | | $ - | $ - | | | $ - | Cost included in treatment quote |
| Site Orientation | | | | | | | | | | Cost included in treatment quote |
| Survey and Entry | 2 | $ 56.0 | | | | $ 112 | 1 | Each | $ 112 | One HPT at $56/hour |
| Set-Up Equipment | | | | | | $ - | | | $ - | |
| Rigger | 4 | $ 49.67 | | | | $ 199 | 1 | Each | $ 199 | Place hoses |
| Electrician | 2 | $ 49.67 | | | | $ 99 | 1 | Each | $ 99 | Electrical connections |
| | | | | | | | | **Subtotal** | **$ 1,322** | |
| **Mobile Treatment 331.12.05** | | | | | | | | | | |
| Treatment | | | | | 50000 | 50000 | 1 | Each | $ 50,000 | Treatment of 24000 gallons (assumes 2 weeks on site) |
| Sampling & Testing | 0.50 | $ 49.67 | 0.00 | $ - | $ 250 | $ 275 | 8 | Sample | $ 2,199 | 2 samples/ day for 4 days of operation |
| Health Physics (HPT) | 40.00 | $ 56.00 | | | | $ 2,240 | 1 | Each | $ 2,240 | |
| Protective Clothing (PCs) | 0.00 | $ - | 0.00 | $ - | $ 9.85 | $ 46 | 2 | Each | $ 93 | Splash protective suit |
| | | | | | | | | **Subtotal** | **$ 54,531** | |
| **DEMOBILIZATION WBS 331.21** | | | | | | | | | | |
| Decon & Prep for Trans | 0.00 | $ - | | | $ - | $ - | | | $ - | |
| Rigger | 16.00 | $ 49.67 | 0.00 | $ - | $ - | $ 795 | 1 | Each | $ 795 | |
| Health Physics (HPT) | 16.00 | $ 56.00 | 0.00 | $ - | $ - | $ 896 | 1 | Each | $ 896 | |
| Transportation | | | | | | | | | | Included in Treatment quote |
| | | | | | | | | **Subtotal** | **$ 1,691** | |
| **Waste Disposal WBS 331.18** | | | | | | | | | | |
| Disposal | | | | | $ 53 | $ 53 | 18.3 | ft3 | $ 968 | Low Level Waste Disposal |
| | | | | | | | | **Subtotal** | **$ 968** | |
| **Procurement Cost** | | | | | | | | | | |
| Procurement Cost | | | | | 4650 | 4650 | 1 | Each | **$ 4,650** | 9.3%for contract administration |
| | | | | | | | | | **$ 4,650** | |

Note: TC = UC * TQ **INNOVATIVE** **TOTAL:** **$ 63,162**

## EQUIPMENT RATES

### Computation of Government Owned Equipment Rates

### Hourly Rates for Government Owned Equipment

The computation of an hourly rate which represents the Government's ownership of a piece of equipment (in this case EMPORE and the evaporation treatment facility) is based on general guidance contained in Office of Management and Budget (OMB) circular No. A-94 for Cost Effectiveness Analysis. The hourly rates for equipment consist of:

- Ownership Costs
- Operating Costs
- Fuel, Filters, Oil, Grease and other consumable items
- Repairs, maintenance, overhauls and calibrations

The hourly rates for Government owned equipment considered in this analysis are based on amortizing the initial purchase price, including shipping cost, over the service life of the equipment using a discount rate prescribed in the OMB circular No. A-94 of 5.8%.

Consumable items, such as tool bits or hoses, may not appear in this hourly rate if the consumable quantity varies from situation to situation. Rather, the observed quantity for the consumable is shown as a line item in the analysis summary table (Table 5.1 and Table 5.2) so that a potential technology user is alerted to this cost item and can evaluate the appropriate cost for the conditions at his site.

The potential salvage value for the equipment is not included in this analysis. The salvage value is excluded because it is anticipated that the equipment will be disposed of at the conclusion of its useful life. The potential cost of decontamination of the equipment makes recycling unlikely.

The use rate is either based on historical experience (for example some of the radiological survey instruments currently used at ANL have been in service for the past 15 years), amount of use determined from a survey of rental firms for the specific equipment item, or based on engineering judgment.

The computation of the hourly rates for each piece of equipment is shown on the following spread sheets.

**Computation of Hourly Rate for Government Ownership Empore™**

| **Assumptions:** | |
|---|---|
| Nominal Discount Rate | 5.8% |
| Equipment Use Rate (hr/yr) | 3504 |
| Procurement Cost | 9.3% |

| **Equipment Identification** | |
|---|---|
| Mfg. | ANL |
| Model # | 0.5 GPM |
| Description | EMPORE |

| **Compute Hourly Rate** | | |
|---|---|---|
| Purchase Price | $ | 13,618 |
| Salvage Value (1) | _ $0.0 | |
| Procurement Cost (2) | $ | 1,266 |
| Amount to be Amort. | $ | 14,884 |
| | | |
| Service Life Hours (3) | | 20000 |
| Service Life (years) | | 5.707762557 |
| | | |
| Amortized Purchase | | $0.90 |
| | | |
| | | |
| Annual Repair Cost | $ | 500.00 |
| Hourly Repair Cost | | |
| | | |
| Operation Cost ($/hr) | | |

| **Total Hourly Rate** | **$0.90** |
|---|---|

**Computation of Use Rate**

Days / Year = 365

Continuous Operation Hours = 365 days X 24 hr/day=8760 hrs/year

Adjusted Operation ( for Utilization of 40%)= 40% X 8760=3504 hr

**Per Day Cost for Amortization**

$0.90/hr X 24 hr/day=$21.60 / day

**Per Gallon Cost for Amortization**

$21.60/day / (0.5 gal/min X 60 min/hr X 22 hr/day)=$0.033/gal

Assumes down time of 2 hrs/day

Notes:

1. Assumes equipment is disposed of rather than decontaminated for recycling, no salvage value
2. Procurement costs for ANL (preparation and award of contract) is 9.3% of purchase price, site variable
3. Service life based on existing equipment life and anticipated obsolescence
4. Costs are developed for amortizing over an 8 hour day (2000 hours per year) despite 24 hr operation
5. Amortized purchase and procurement costs based on analysis and interest rate from OMB Circular No. A-94
6. Operation costs may be shown on the summary tables in section 5 rather than here to highlight some issues

**Computation of Hourly Rate for Government Ownership For Evaporator Facility**

| **Assumptions:** | |
|---|---|
| Nominal Discount Rate | 5.8% |
| Equipment Use Rate (hr/yr) | 6570 |
| Procurement Cost | 9.3% |

| **Equipment Identification** | |
|---|---|
| Mfg. | ANL |
| Model # | Evaporator |
| Description | 700 gal/day |

**Computation of Use Rate**

Days / Year = 365

Continuous Operation Hours = 365 days X 24 hr/day=8760 hrs/y

Adjusted Operation ( for down time of 25%)= 75% X 8760=6570

| **Compute Hourly Rate** | | |
|---|---|---|
| Purchase Price | $ | 400,000 |
| Salvage Value (1) | _ $0.0 | |
| Procurement Cost (2) | $ | 37,200 |
| Amount to be Amort. | $ | 437,200 |
| | | |
| Service Life Hours (3) | | 130000 |
| Service Life (years) | | 19.7869102 |
| | | |
| Amortized Purchase | | $5.74 |
| | | |
| | | |
| Annual Repair Cost | | |
| Hourly Repair Cost | | |
| | | |
| Operation Cost ($/hr) | | |

| **Total Hourly Rate** | **$5.74** |
|---|---|

**Per Day Cost for Amortization**

$5.74/hr X 24 hr/day=$137.76 / day

**Per Gallon Cost for Amortization**

$137.76/day / 700 gal/day=$0.2 / gal

**Per Gallon Cost for Amortization & Operation**

$0.2 / gal + $3.00 / gal = $ 3.20 /gal

Notes:

1. Assumes equipment is disposed of rather than decontaminated for recycling, no salvage value
2. Procurement costs for ANL (preparation and award of contract) is 9.3% of purchase price, site variable
3. Service life based on existing equipment life and anticipated obsolescence
4. Costs are developed for amortizing over an 8 hour day (2000 hours per year) despite 24 hr operation
5. Amortized purchase and procurement costs based on analysis and interest rate from OMB Circular No. A-94
6. Operation costs may be shown on the summary tables in section 5 rather than here to highlight some issues